ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 4, Issue 12, December 2015

ISAR Imaging using Doppler Processing Algorithm for Moving Targets

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***Abstract*— Inverse Synthetic Aperture Radar (ISAR) is used to produce high resolution imagery of non-cooperative targets by retrieving the relative motion parameters of a target with respect to a reference. This concept of estimating motion parameters is applied for obtaining cross-range resolution in ISAR imaging in which one component is produced by the relative motion between the radar and the target and other from the independent ambulatory characteristics of manoeuvring targets. Thus, a highly resolved ISAR image is produced through pulse compression and motion compensation using these point estimates. This paper deals with the modelling of basic MATLAB based signal processing system for Linear FMCW (frequency modulated continuous wave) radars taking chirp signal as input and obtaining accurate motion parameters (point estimates) using the Range-Doppler algorithm based on the 2-D Fourier transform**

***Keywords*— ISAR Imaging, Range-Doppler, Linear FMCW, high-resolution Imagery**

I. INTRODUCTION

The performance of any Radar system depends on certain parameters such as Range resolution, accuracy of point estimates and Target detection & its recognition. Other factors include its signal detection capabilities during interference from clutter echoes and other atmospheric effects and also its propensity to mark a distinction between any inadvertent interfering signals from other neighboring hospitable transmitters and any other intended radiations from vicious jamming (be it any military radar or ballistic missiles).

Inverse Synthetic Aperture Radar (ISAR) is a powerful signal processing technique employed for the identification and classification of targets by a figurative distribution of dominant scattering regions, known as scattering centres of the target and thus producing a standard 2D ISAR image by collecting the scattered field for different look angles and Doppler histories.[1][2] Hence, a 2D ISAR image is just a graphical representation of range profiles in one axis and cross-range profiles in other axis keeping in consideration the scattered field for different look angles and Doppler frequencies.

II. PROBLEM STATEMENT

ISAR projection of a target is obtained as a result of its rotational motion. In case of fast moving targets such as jet aircrafts or the targets undergoing rotational motion typically the pitching of ship, the retrieval of information dealing with point estimates in effect with the relative motion of target and the reference surface becomes complex. One of the major concerns with the ISAR imaging is that the conventional Range-Doppler ISAR technique is not effectual when target motion generates higher order labels in the phase of received signal relative to each scatterer. [3] The result of this non-uniformity is distortion which is proportional to the change of instantaneous range of the target. Often, the image integration time is only a few seconds and the target's rotational displacement with respect to a reference is only a few degrees. The result of this is the target projection seen in the ISAR image becomes severely blurred and inconsistent, which make the Target recognition and image reconstruction process a very difficult task.

In order to optimize the computational complexities associated with ISAR imaging and make it viable for practical applications, an approach is introduced based on the assumption that there exists an imaging interlude which elucidates the collaborative effect of target's characteristic motion and the receiver's position i.e. the top or side view of an ISAR image with sufficient cross-range resolution. Through this paper we present our research on production of a well-defined focussed image of a moving target undergoing both rotational and translational motion by estimating the kinematic parameters associated by target's motion in order to compensate their effect on phase of the received echo signal. The principal problem statement of this paper is the modelling of an ISAR target detection system in MATLAB for Linear FMCW (frequency modulated continuous wave) radars taking a chirp signal and applying several calculations to estimate the change in positions of a moving target and eventually observing their range compressed images over cross range.

III. LITERATURE: ISAR IMAGING OF A MOVING TARGET

The basic modelling of Images using Inverse Synthetic Aperture Radar in this paper is studied by including temporal variations of target's motion with respect to its angular rotational rate. High resolution imagery is obtained by applying spectral estimation techniques and by range-Doppler algorithm based on computational methods of Fourier transform (FFT/STFT) for pre-processing raw signal data.
Radar transmits electromagnetic waves to a target and receives the reflected signal from the target. The received signal is then analysed and conclusions regarding the nature,

distance and relative velocity of target of interest are drawn. The carrier modulation is obtained by using FMCW radar which employs frequency modulation at the signal source to enable propagation delay measurements for determination of the distance to the target. [4] In this, linear frequency sweeps are transmitted and target parameters are obtained by continuously combining the delayed echoes with the transmitted signal specimen. The FMCW radar amplifies the received signal and combines it with local oscillator to create a beat. This beat frequency is proportional to the distance.

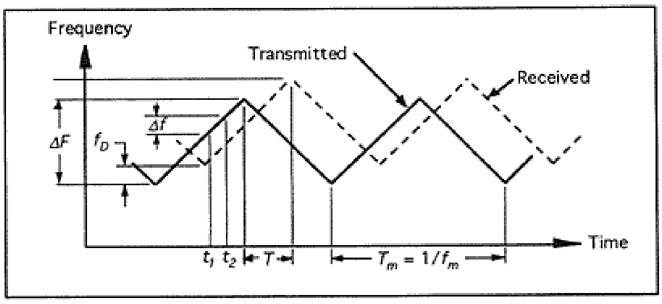

Fig: Illustration of transmitted and received signal in Linear FMCW radar in frequency-time domain

From the above figure, if ΔF is the transmitted signal bandwidth, T_m is the period of the modulator signal, the echo of the target at range R causes a delayed model of the transmitted signal (dotted line), Δf is the frequency difference of the echo and the transmitter, called beat frequency and c is the propagation velocity. The range can be computed from the formula:

$$R = \frac{c*\Delta f*T_m}{2*\Delta F}$$

Once the target's range information is collected; the statistics about the Doppler (cross-range) are estimated. This cumulative approach of Range-Doppler processing makes use of a two-fold feature of two dimensional FFT, one on the samples of each frequency sweeps to translate the de-chirp data into beat frequency domain in order to estimate the range profile and second on the samples of same range cell on consecutive sweeps of the same slope to acquire the Doppler information. For systems perturbed by noise, the optimum detection of signal is carried by means of matched filtering or by customizing the characteristics of window for Doppler weighting in order to reduce the side-lobes in the time domain.

After collecting the range-Doppler information, the next task is to implement the range resolution schemes to distinguish between targets on the same trajectory but in different range. This is achieved by applying pulse compression techniques in which the transmitted signal is modulated and then correlated by the received signal. The ideal range resolution for an FFT is given as:

$$R = \frac{c}{2\Delta F}$$

But due to the presence of certain undermining factors because of filter bandwidth with consequently affects the clutter rejection and transient performance, the range resolution is given considering the number of samples in an FFT interval (N_s).

$$N_s = \frac{2*R_{max}}{\Delta R}$$

The radar signal processing involves the coherent integration of these samples and after gathering information about several parameters such as Resolution, frequency, aspect, the range-Doppler matrix after performing 2D FFT, the positions of looks angles, relative positions of different scattering centres, the final image can be readily obtained by carrying out 2D IFT at the final stage.

IV. Proposed System and Methodology

This paper illustrates the MATLAB modelling of a signal processing system to detect moving targets. In this research, the target's scattering centres are taken as a basis of projecting a 2D ISAR imagery of a manoeuvring target. The relative positions and sizes of the point scatterers are obtained, the information about their range and cross-range profiles are tabulated in a Range-Doppler matrix and a corresponding ISAR image is created using these data. The prime objectives of these series of experimentations are:

- To investigate the practical applications of concepts of ISAR imaging and other underlying principles.
- To study and understand the basic radar signal processing steps, Moving target detection and imaging and Doppler processing.
- To implement the concepts of LMFM radars, techniques of pulse compression and range resolution to study and adjust the signal behaviour and optimize it.
- To apply relevant formulations on noise and other disruptions that hinders the signal reception process.

The first step is Signal phenomenology. This includes deriving both the idiosyncratic physical properties of the target, the parameters such as physical size, orientation, relative size and velocity with respect to the radar and the characteristics peculiar to radar itself. When starting the design procedure, at first the image size is selected, and then according to this, the range and cross-range are extended. If the range extension is X_m and the cross-range extension is Y_m, then the corresponding size of the target to be imaged is selected as X_m*Y_m. After selecting the size of target, the equivalent range and cross-range resolution are computed using the concept of N sampling points. Once these are determined, the resolution, frequency and aspect (ΔØ) are deduced by applying the Fourier concepts. The frequency bandwidth, B and angular width, Ω is calculated and if the frequencies will be centred on f_c and radar look angles around ΔØ, the backscattered electric field at those angles is obtained and final image is formed by taking the 2D IFT.

V. Implementation

In this project, an integrated platform is designed which can be used to simulate and examine the characteristics of a moving target and ISAR images are produced by taking certain radar parameters such as frequency of chirp signal (GHz), frequency bandwidth of chirp (GHz), Pulse duration of single chirp and target parameters such as radial translational velocity of target, initial x and y coordinates and target's size in range and cross-range as input.

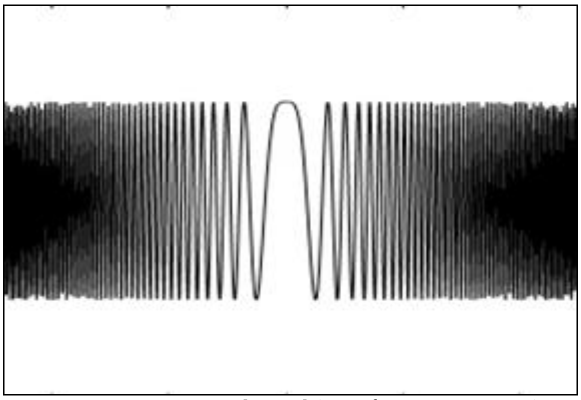

Fig: Transmitted Signal (LFM frequency = 7 GHz)

A. ISAR Imaging of a Pitching Ship:

In case of a pitching ship, the target undergoes rotational motion such that relative position of scatterers in each down-range is same over a specific integration time. If N pulses are transmitted over a specific integration period, then there are N range profiles that can be estimated for different burst indices. Since, the scattering centres on the ship are constantly changing due to its pitching motion, the aspect and look angles also changes. Hence, in this case the Doppler frequency depends upon the relative change in position of scatterers with respect to centre of rotation.

The radar and target parameters are given as input in the GUI, the designated call back is executed and plots representing the range-compressed image and its final image are obtained.

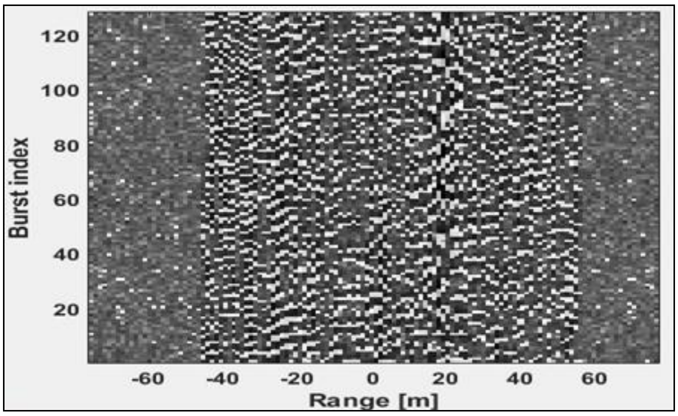

Fig: Range Compressed Image of the Target

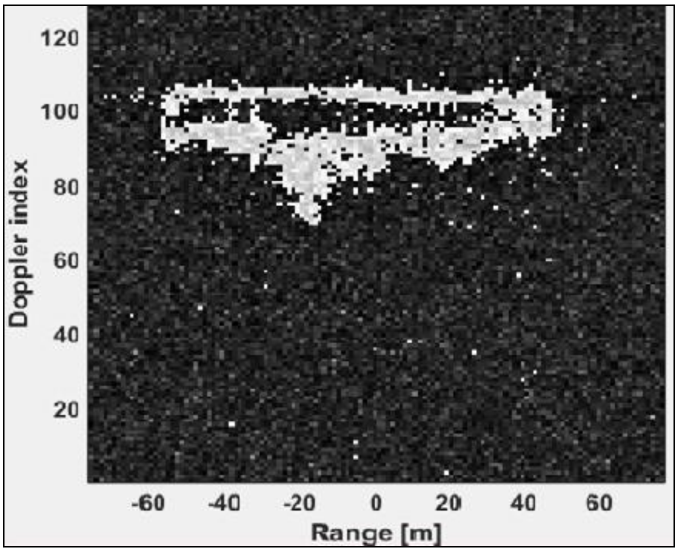

Fig: ISAR image of a pitching ship

B. ISAR Imaging of an Aircraft:

For an aircraft target, the factor in its recognition is the radar platform. Several Non-cooperative target recognition techniques such as Jet engine modulation (JEM) and High range resolution (HRR) can be employed to detect a flying aircraft. The relative speed with respect to radar platform is observed and the statistics about its initial x and y coordinates and target size in range and cross range is calculated. The change in aspect angle due to its motion is recorded and accordingly Range-Doppler matrix is designed.

The radar and target parameters are given as input in the GUI, the designated call back is executed and plots representing the range-compressed image and its final image are obtained.

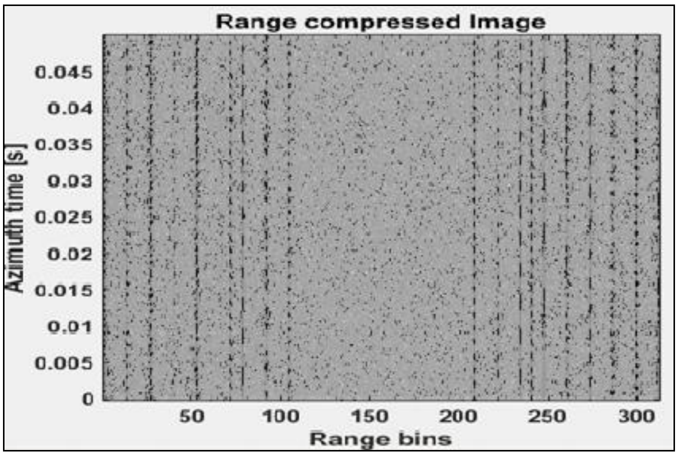

Fig: Range Compressed Image of the Target

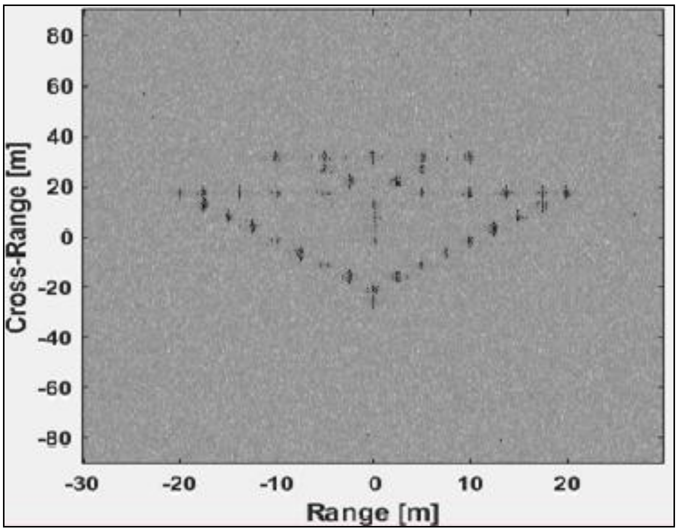

Fig: ISAR Image of an Aircraft

C. *ISAR Imaging of ground targets:*

In case of Land vehicles and people, the NCTR techniques of High range resolution and spectral analysis is generally used. The motion compensation attributes are studied and corresponding range-Doppler profiles are recorded.

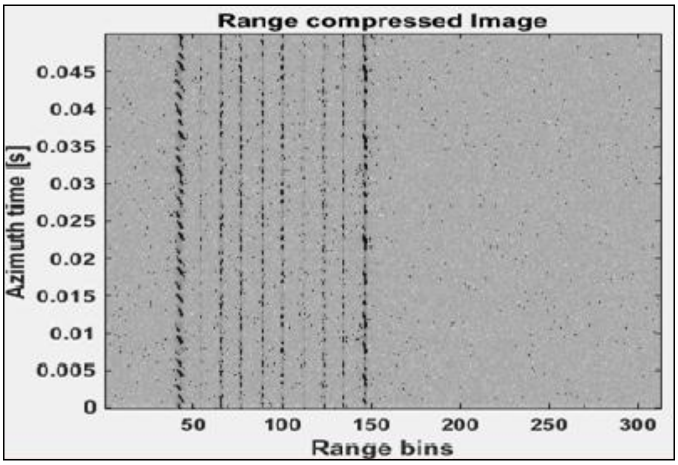

Fig: Range Compressed Image of the Target.

In case of Ground based targets, techniques such as Moving target Indication (MTI/ MTI SAR) can also be employed. The signal conditioning and Interference suppression can be achieved by clutter rejection, noise suppression, etc.

VI. Conclusion

The observations demonstrate ISAR imaging of moving targets with respect to different radar platforms using Range-Doppler algorithm based on conventional 2D Fourier transform. The concepts behind the radar signal processing and motion compensation techniques are studied. The detections were realized by transmitting a LFM (chirp) signal and observing its response when hit by the target. The distributed point scatterers were taken as a basis and their relative change in position and change in range profiles were recorded. However, the scope of radar signal processing and its applications is extensive. New techniques are introduced for detection and recognition and numerous researches are being carried out in this profound subject. Through this paper, we make an effort to study and apply some of the core concepts of ISAR imaging and signal processing through a MATLAB based interactive platform for ease of use.

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